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MEMORANDUM REPORT NO. 1354
JUNE 1961

THE EFFECTS OF MAGNUS MOMENT AT SUBSONIC VELOCITIES ON THE 105MM MORTAR PROJECTILE T-53

Maynard Piddington

Department of the Army Project No. 503-03-001
Ordnance Management Structure Code No. 5010.11.814

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

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A B E R D E E N   P R O V I N G   G R O U N D,   M A R Y L A N D

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MPiddington/clw
Aberdeen Proving Ground, Md.
June, 1961

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ABSTRACT

An analysis of the performance of the 105mm mortar shell T-53 with T10E5 fins, at subsonic velocities, is presented and discussed. Emphasis is focused on the effect of Magnus moment. This shell, representative of one type of fin stabilized projectile, has an eight-bladed fin assembly with a span of one caliber, and has a low-drag, streamlined body. The performance of the T-53 is of particular interest, because little is known about Magnus in the subsonic region. The Magnus moment derivative, $C_{M_{p\alpha}}$, varied from 2.3 at $\phi' = 13$ to 4.5 at $\phi' = 27$. These values are several times larger than those experienced by spin stabilized projectiles. It was found that the static moment derivative, C_{M_α}, was also a function of spin.

TABLE OF CONTENTS

I. TABLE OF SYMBOLS

a_2		Slope of the curve in figure 4 (per radian squared)
b_2		Slope of the curve in figure 7 (per radian squared)
C_D	=	$\dfrac{\text{Drag force}}{qS}$
$C_{D_{\delta}2}$		Zero yaw drag derivative (per radian squared)
C_{L_α}	=	$\dfrac{\text{Lift force}}{qS\alpha}$
C_{M_α}	=	$\dfrac{\text{Static moment}}{qS\ell\alpha}$
$C_{M_q} + C_{M_{\dot{\alpha}}}$	=	$\dfrac{\text{Damping moment}}{qS\ell\left(\dfrac{q\ell}{V}\right)}$
$C_{M_{p\alpha}}$	=	$\dfrac{\text{Magnus moment}}{qS\ell\left(\dfrac{p\ell}{V}\right)\alpha}$
d		Missile diameter (inches)
I_x		Axial moment of inertia (lbs. - in^2)
I_y		Transverse moment of inertia (lbs. - in^2)
K_1		Magnitude of slow arm (radians)
K_2		Magnitude of fast arm (radians)
ℓ		Reference length, $\ell = d$ (inches)
q	=	$1/2\ \rho V^2$
S	=	$\pi\ d^2/4$
V		Velocity of missile (feet per second)
Wt.		Weight of missile (lbs.)
α		Angle of attack (degrees)

I. TABLE OF SYMBOLS (continued)

δ^2	=	$K_1^{\ 2} + K_2^{\ 2}$ (mean squared yaw) (radians squared)
$\delta_e^{\ 2}$	=	$K_1^{\ 2} + K_2^{\ 2} + \dfrac{K_1^{\ 2}\,\phi_1' - K_2^{\ 2}\,\phi_2'}{\phi_1' - \phi_2'}$ (radians squared)
$\delta_{e_1}^{\ \ 2}$	=	$K_1^{\ 2} + 2\,K_2^{\ 2}$ (radians squared)
λ_1, λ_2		Damping rates (1/foot)
ρ		Air density (lbs. per cubic foot)
ϕ'		Spin (degrees per foot)
ϕ_1'		Turning rate of slow arm (degrees per foot)
ϕ_2'		Turning rate of fast arm (degrees per foot)

II. INTRODUCTION

It has become fairly standard practice to launch fin stabilized ammunition with a small amount of spin so as to average out the effects of fin misalignment caused either by machining inaccuracies or during launch.[1] Spin, however, produces a Magnus torque which could lead to dynamic instability. While this Magnus problem has been known to exist, it had generally been thought to be a problem only when the spins were much larger than were employed in practice.

Limited Magnus data have been obtained on several fin stabilized models, both spiked-nosed and streamlined, particularly at supersonic velocities. In some cases, the spin has caused dynamic instability at spins as low as that of resonance.[2] Hence, the effects of spin on this type of shell must be considered an important factor in the design of a model so that stable flight can be assured.

The main purpose of this report is to present additional Magnus information pertaining to one of the several types of fin stabilized projectiles. The projectile selected for this test was the 105mm mortar shell T-53. This shell has a fin span of one caliber and a streamlined, low drag body. The rounds were fired for a mid-range velocity of 900 ft/sec. - a region in which very little is known about Magnus effects.

Eleven rounds were fired through the Transonic Range[3] of the Ballistic Research Laboratories. Three guns were used in which spins of 13, 22 and 27 degrees per foot were obtained. Unfortunately, only drag and static moment data were obtained at the 22 level. A drawing of the T-53 and some of its physical properties are given in Figure 1, and a photograph of the shell in flight in Figure 2. Standard drag, yaw and swerve reductions[4] were performed; the results are given in the Table of Aerodynamic Data and in Figures 3 through 8.

III. RESULTS

The normal drag, yaw and swerve reductions yield considerably more than merely Magnus data. This additional information is also presented in this section mainly to supplement the data reported on in Reference 5.

1. Drag Force Coefficient

The drag force coefficient, C_D , is plotted in Figure 3 versus mean squared yaw, δ^2 . It is assumed that the Mach number effect on C_D is negligible. For some unexplained reason the data points appear to make up two distinct curves. One curve is about 5.5% lower than the other. Since each curve contains drag values obtained from rounds of different spin, spin is not considered a variable. No evidence which would logically explain the discrepancy in drag could be observed in the shadowgraphs of the shell in flight. This may mean that, because of the velocity of the projectile and the texture of the photographs, any flow phenomenon which could cause the discrepancy was not observable (note Figure 2). Another possible explanation is that the rounds may have come from separate lots and hence, may have had some slight manufacturing differences. Again, there is no evidence to back this up. The zero yaw drag derivative, $C_{D_{\delta^2}}$, in each case is about 9 per radian squared.

2. Righting Moment Derivative

The righting moment derivative, C_{M_α} , is plotted versus the effective squared yaw in Figure 4. Again, no Mach number correction was made, but obviously there is a variation with spin. Assuming that the moment derivative variation with yaw is of the form $C_{M_\alpha} = (C_{M_\alpha})_o + a_2 \delta_e^2$, $(C_{M_\alpha})_o$ can be plotted as a function of spin (Figure 5).

By using Figures 4 and 5, one can easily determine the static moment derivative for any reasonable spin and yaw.

One high spin C_{M_α} data point, at $\delta_e^2 = .00027$, appears to be considerably higher than the curve drawn for that group. No reason can be given to explain this large discrepancy.

3. Damping Moment Derivatives

The damping moment derivatives, $C_{M_q} + C_{M_{\dot{\alpha}}}$, are given in the Table. $C_{M_q} + C_{M_{\dot{\alpha}}}$ are evaluated from a combination of both arms and hence, their accuracy depends upon how well the damping of the fast and slow rates are determined. $C_{M_q} + C_{M_{\dot{\alpha}}}$, within its scatter, appears to be fairly constant at about 55.

4. Lift Force Derivative

The lift force derivative, C_{L_α}, appears to be fairly constant at about 3.0.

5. Magnus Moment Derivative

Perhaps the greatest effect of spin can be observed in the damping of the slow arm. It should be pointed out that when a Magnus torque is present it will adversely affect one of the damping rates and cause the other rate to damp faster than if no spin were present. As a result, one of the arms, in this case the slow arm, will have a much better determination than the other. This rate is plotted versus $\delta_{e_1}^{2}$ in Figure 6. It can be observed from these curves that the damping of the slow rate varies with both yaw and spin. This curve also indicates that to insure dynamic stability spins no greater than 18 deg/ft should be employed.

The Magnus moment derivative, $C_{M_{p\alpha}}$, is plotted versus δ_e^{2} in Figure 7. Assuming that the $C_{M_{p\alpha}}$ variation with yaw is of the form $C_{M_{p\alpha}} = (C_{M_{p\alpha}})_o + b_2 \delta_e^{2}$, $(C_{M_{p\alpha}})_o$ can be plotted versus the spin as shown in Figure 8. There seems to be a definite correlation with spin. A value of about 2.3 was obtained for the low spin group and about 4.5 for the high spin group.

$C_{M_{p\alpha}}$ values of the size obtained in this test are several times

larger than those experienced by spin stabilized projectiles. While this is not necessarily disastrous by itself, it does limit the amount of spin that can be safely employed for shell of this general type.

Maynard Piddington
MAYNARD PIDDINGTON

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2. Piddington, Maynard J. The Effects of Spin and Magnus Torque on a Spiked-Nose, Fin Stabilized, HEAT Projectile - 76mm T180E23. BRL M 1310, Confidential, 1960.

3. Rogers, Walter K., Jr. The Transonic Free Flight Range. BRL Report 1044, 1958.

4. Murphy, Charles H. Data Reduction for the Free Flight Spark Ranges. BRL Report 900, 1956.

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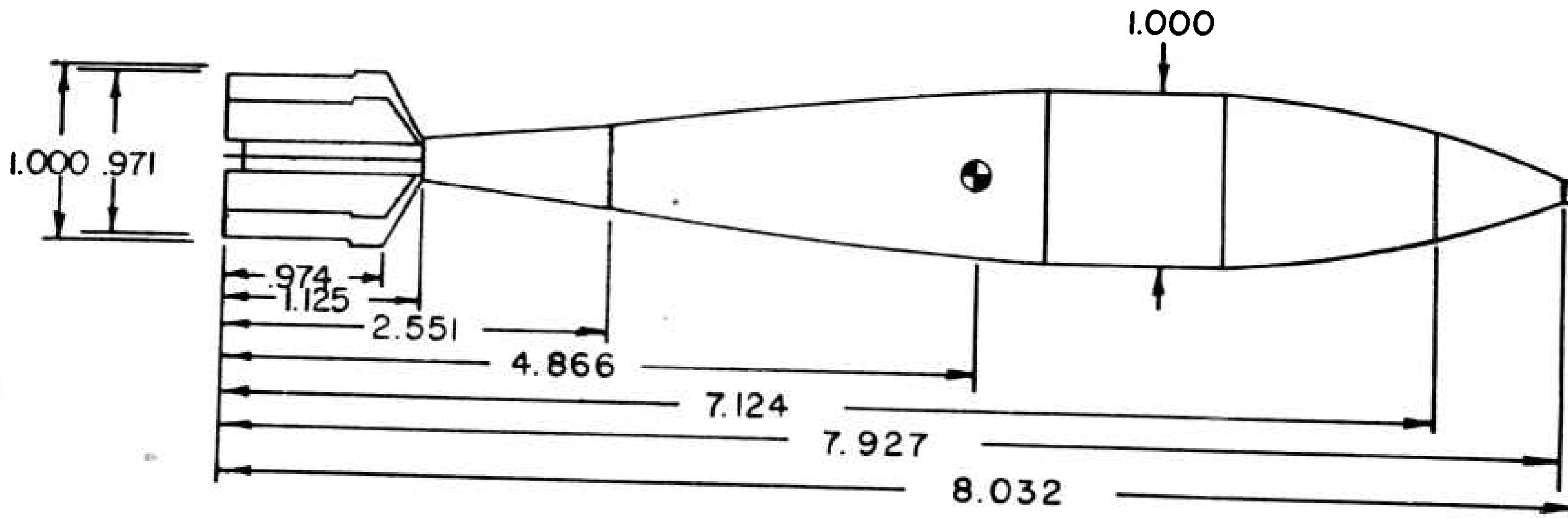
TABLE OF AERODYNAMIC DATA

M	ϕ' (deg/ft)	δ^2 (rad)	C_D	C_{M_α}	$C_{M_q} + C_{M_{\dot{\alpha}}}$	C_{L_α}	$C_{M_{p\alpha}}$	$\lambda_1 x10^3$ (1/ft)	$\lambda_2 x10^3$ (1/ft)	ϕ'_2 (deg)	ϕ'_1 (deg)	K_2 (rad)	K_1 (rad)	Range Rd
.755	27	.00124	.177	-4.347	-71	3.23	-5.1	-.78	5.01	2.19	- .99	.004	.035	4839
.816	25	.00092	.185	-4.380	-51	2.97	-4.5	-.75	3.70	2.11	- .99	.004	.030	5108
.817	26	.00018	.182	-4.530						2.14	-1.01	.003	.013	5109
.818	28	.00234	.202	-4.586	-61	3.08	-4.2	-.59	4.09	2.23	-1.01	.006	.048	4837
.839	28	.00277	.203	-4.545	-59	2.98	-4.0	-.53	3.94	2.21	-1.00	.008	.052	4838
.846	22	.00015	.183	-4.10						1.96	-1.00	.002	.012	5110
.790	13	.00009	.179											4834
.808	13	.00058	.184	-3.891	-50	3.13	-3.26	.50	2.42	1.68	-1.12	.007	.023	4833
.818	13	.00181	.184	-3.998	-54	2.80	-1.93	.86	2.22	1.70	-1.12	.021	.037	5105
.826	13	.00164	.186	-4.194	-59	2.92	-2.33	.85	2.44	1.73	-1.14	.022	.034	5106
.824	14	.00266	.194	-4.254	-52	3.33	-2.07	.80	2.21	1.74	-1.15	.027	.044	5104
		Average error		1.5%	9.5%	5.6%	10%							

PHYSICAL PROPERTIES
105-mm T53



I_x	51.31 lb-in²
I_y	1171.9 lb-in²
WT.	25.35 lbs.
⊕	CENTER OF MASS

NOTE: ALL DIMENSIONS ARE IN CALIBERS

FIG. 1

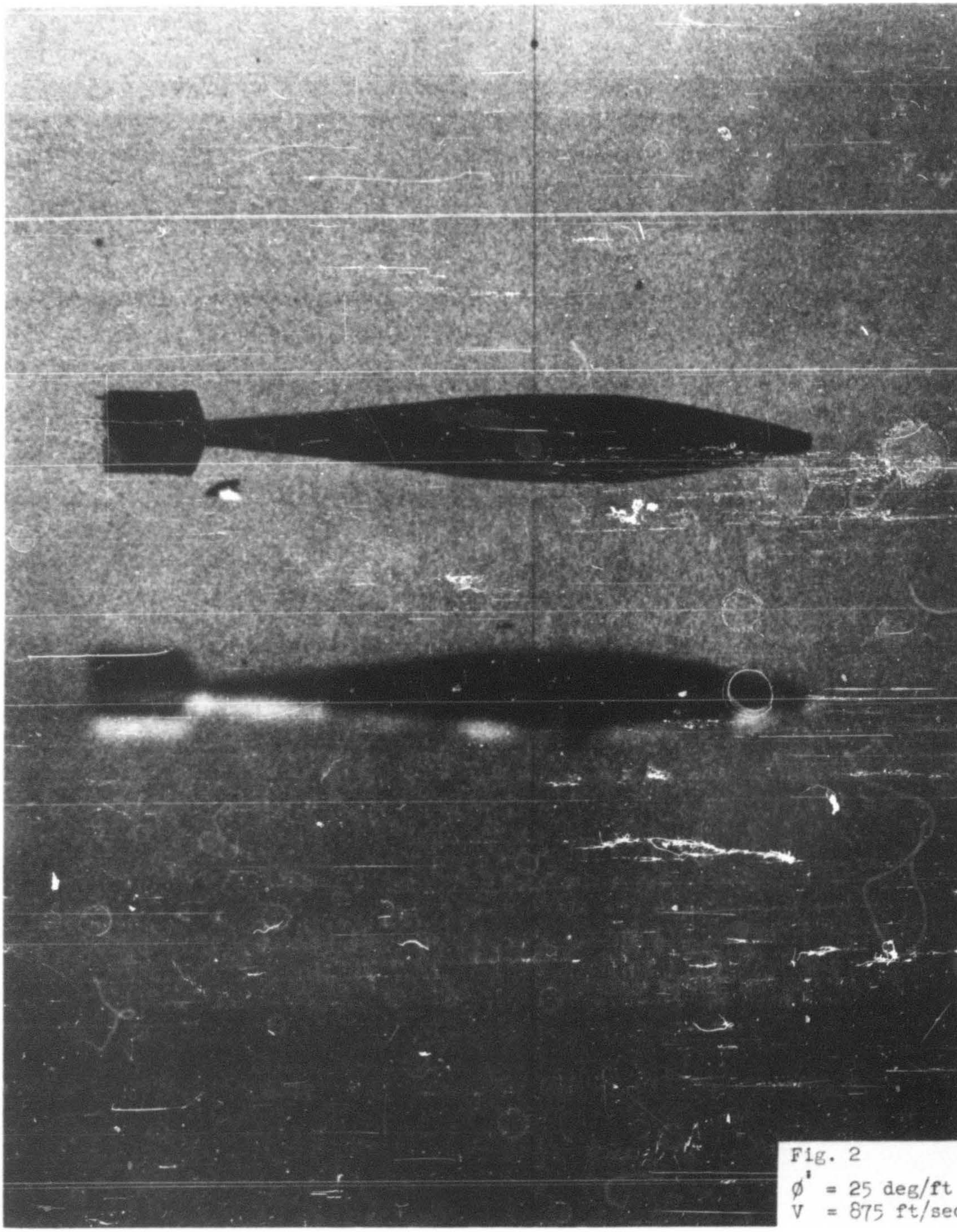
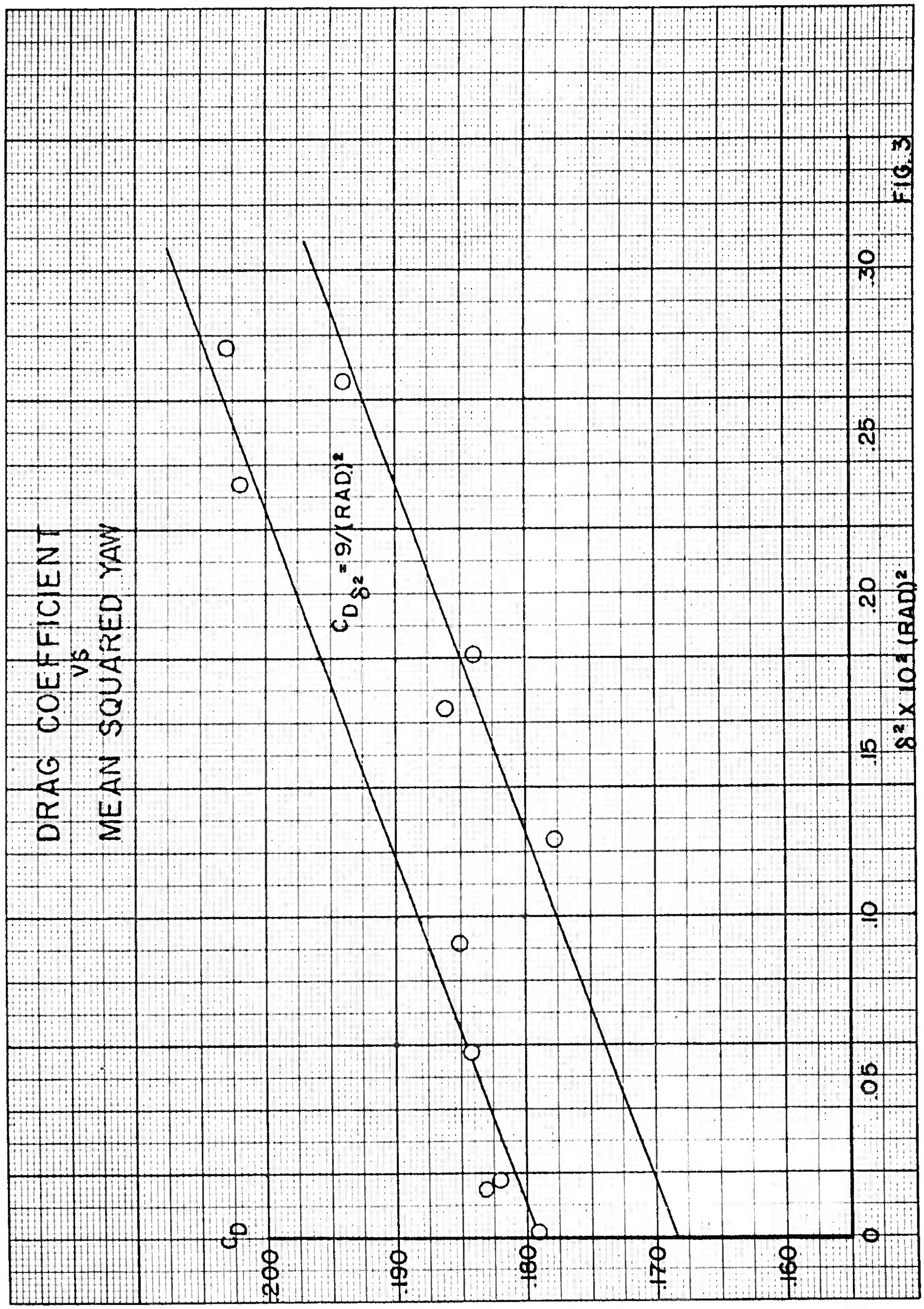
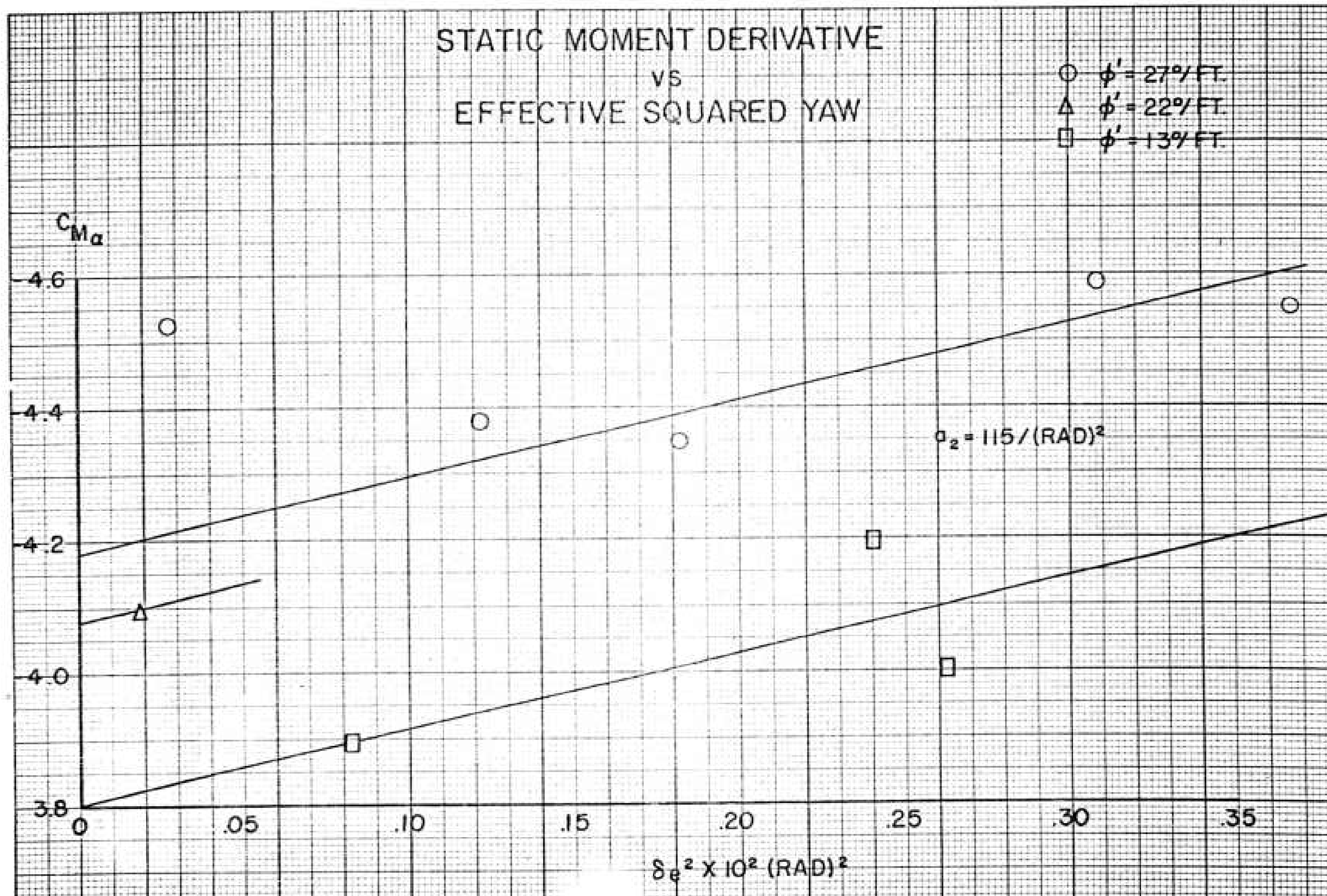


Fig. 2
$\phi' = 25$ deg/ft
$V = 875$ ft/sec



DRAG COEFFICIENT
VS
MEAN SQUARED YAW
C_D
$C_{D_{\delta^2}} = 9/(RAD)^2$
.200
.190
.180
.170
.160
0
.05
.10
.15
.20
.25
.30
$\delta^2 \times 10^2$ (RAD)^2

FIG. 3



STATIC MOMENT DERIVATIVE
VS
EFFECTIVE SQUARED YAW
$\phi' = 27°/FT.$
$\phi' = 22°/FT.$
$\phi' = 13°/FT.$
C_{M_α}
4.6
4.4
4.2
4.0
3.8
0
.05
.10
.15
.20
.25
.30
.35
$a_2 = 115/(RAD)^2$
$\delta_e^2 \times 10^2\ (RAD)^2$

FIG. 4

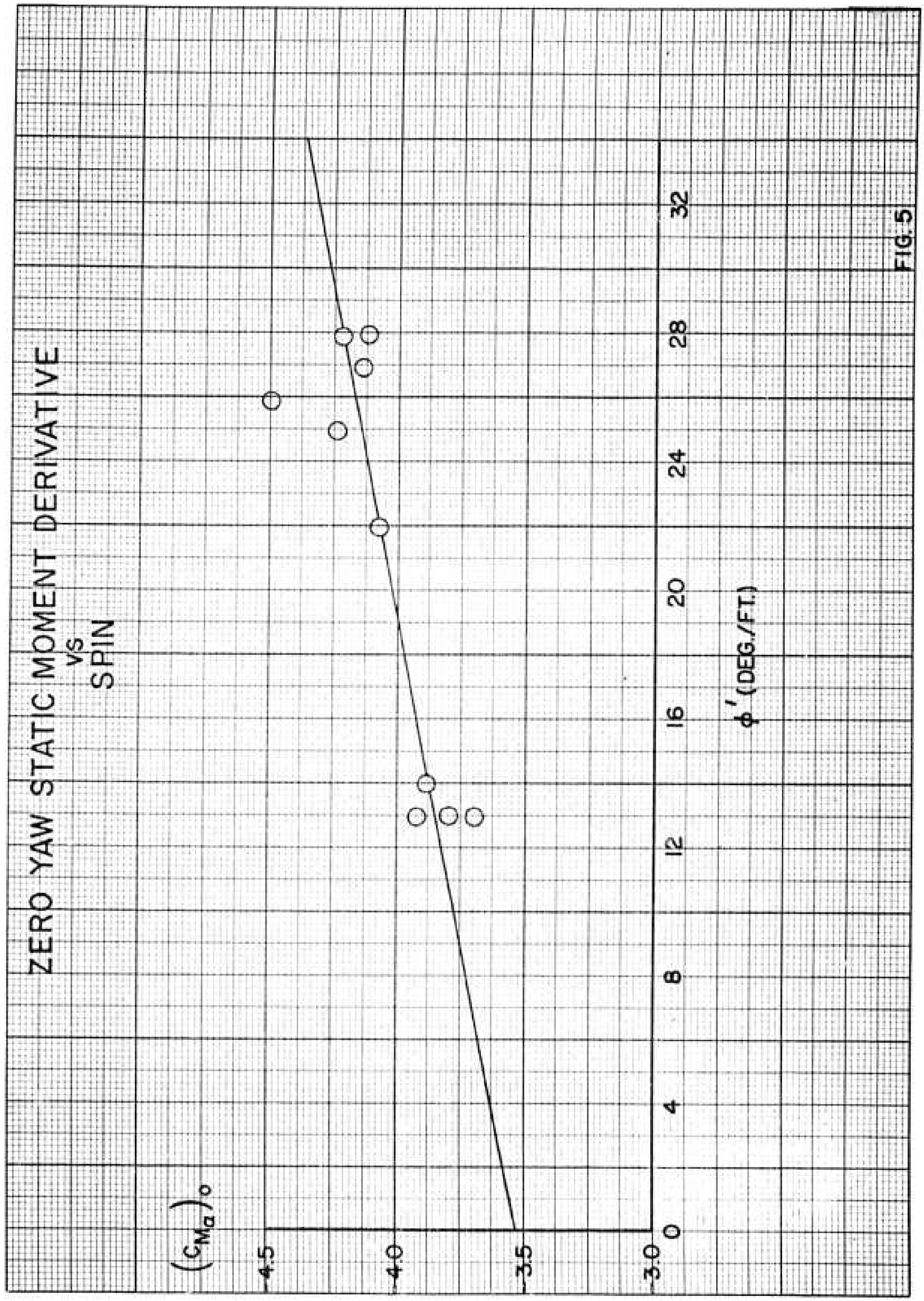
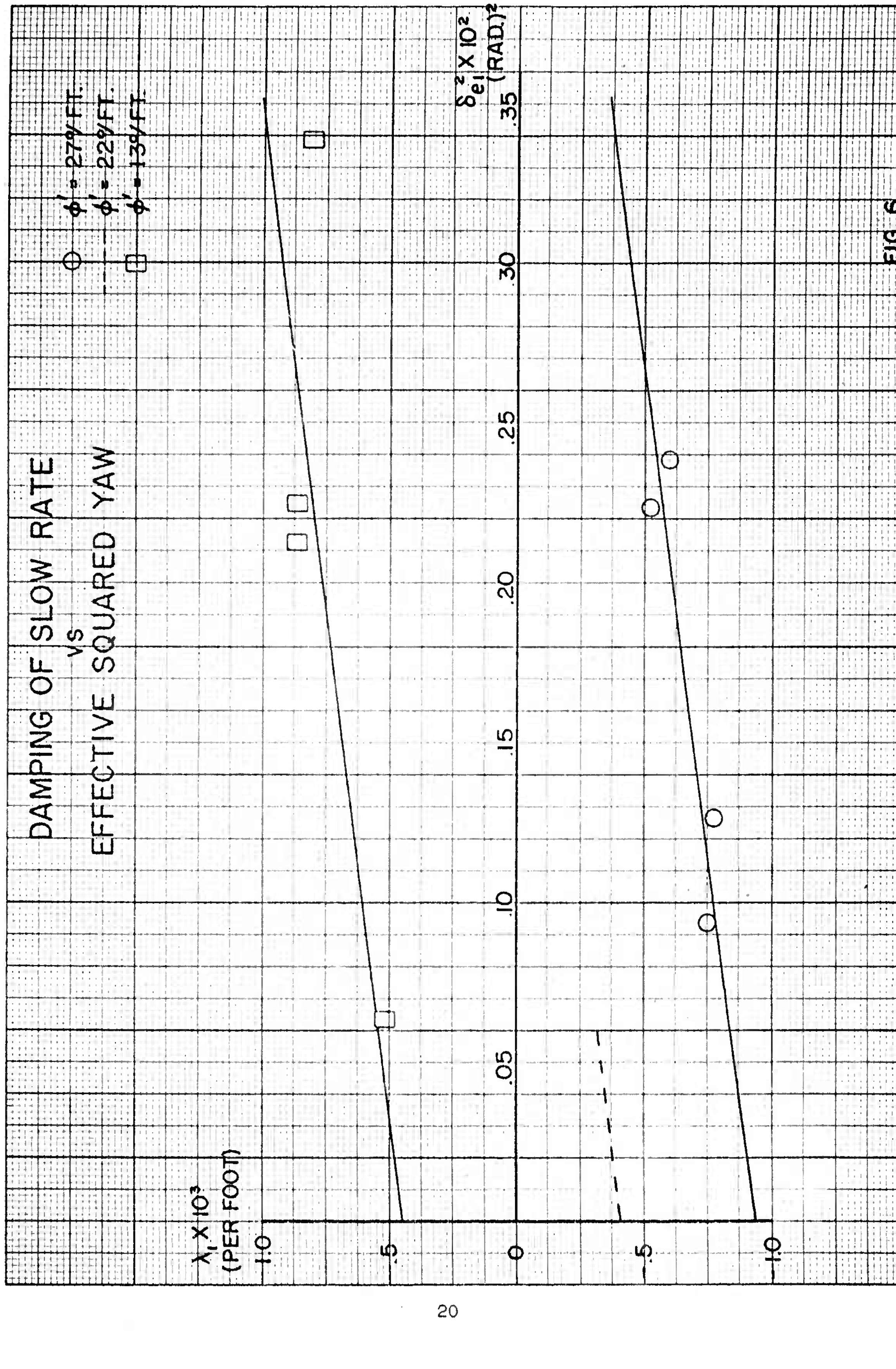

ZERO YAW STATIC MOMENT DERIVATIVE
VS
SPIN
$(C_{M_\alpha})_o$
-4.5
-4.0
-3.5
-3.0
0
4
8
12
16
20
24
28
32
ϕ' (DEG./FT.)

FIG. 5


DAMPING OF SLOW RATE
vs
EFFECTIVE SQUARED YAW
ϕ' = 27°/FT.
ϕ' = 22°/FT.
ϕ' = 13°/FT.
λ1 X 10³
(PER FOOT)
δe1² X 10²
(RAD.)²
1.0
.5
0
.5
1.0
.05
.10
.15
.20
.25
.30
.35
FIG. 6

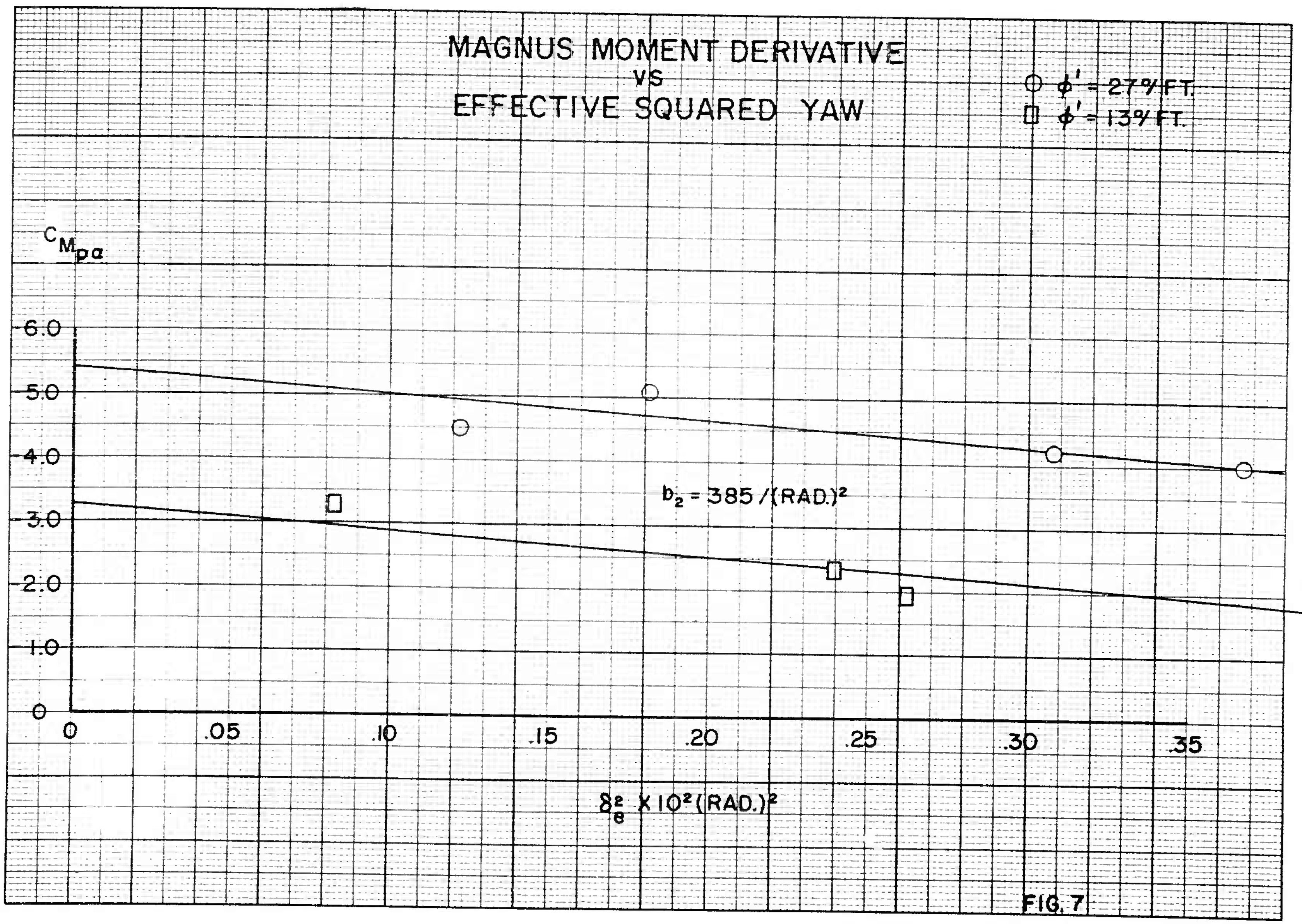
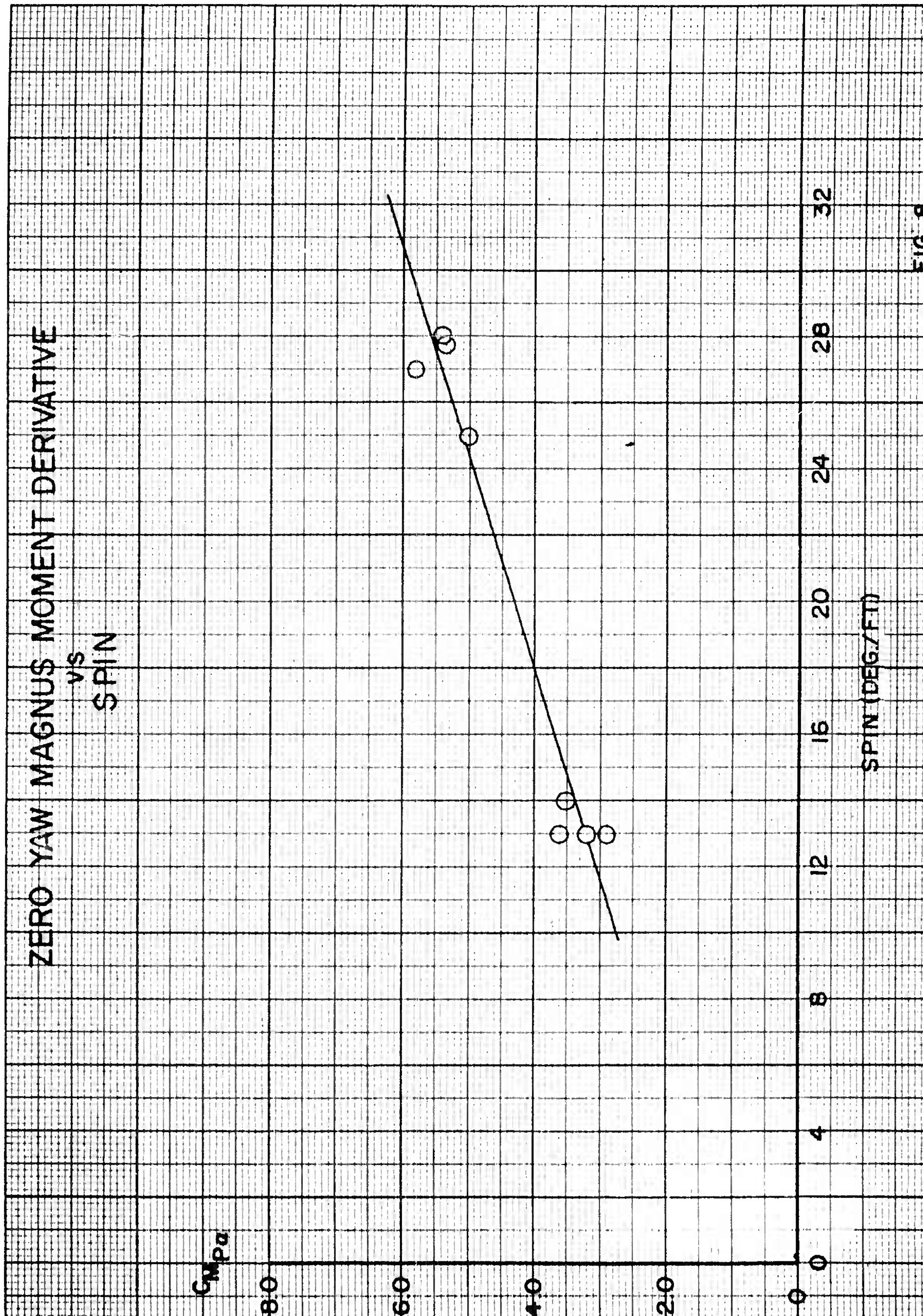

MAGNUS MOMENT DERIVATIVE
VS
EFFECTIVE SQUARED YAW
$\phi' = 27°/FT.$
$\phi' = 13°/FT.$
$C_{M_{p\alpha}}$
6.0
5.0
4.0
3.0
2.0
1.0
0
$b_2 = 385/(RAD.)^2$
0
.05
.10
.15
.20
.25
.30
.35
$\delta_e^2 \times 10^2 (RAD.)^2$

FIG. 7


ZERO YAW MAGNUS MOMENT DERIVATIVE
vs
SPIN
$C_{M_{p\alpha}}$
8.0
6.0
4.0
2.0
0
0
4
8
12
16
20
24
28
32
SPIN (DEG./FT.)
FIG. 8

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An analysis of the performance of the 105mm mortar shell T-53 with T10E5 fins, at subsonic velocities, is presented and discussed. Emphasis is focused on the effect of Magnus moment. This shell, representative of one type of fin stabilized projectile, has an eight-bladed fin assembly with a span of one caliber, and has a low-drag, streamlined body. The performance of the T-53 is of particular interest, because little is known about Magnus in the subsonic region. The Magnus moment derivative, $C_{M_{p\alpha}}$, varied from 2.3 at $\phi' = 13$ to 4.5 at $\phi' = 27$. These values are several times larger than those experienced by spin stabilized projectiles. It was found that the static moment derivative, C_{M_α}, was also a function of spin.

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